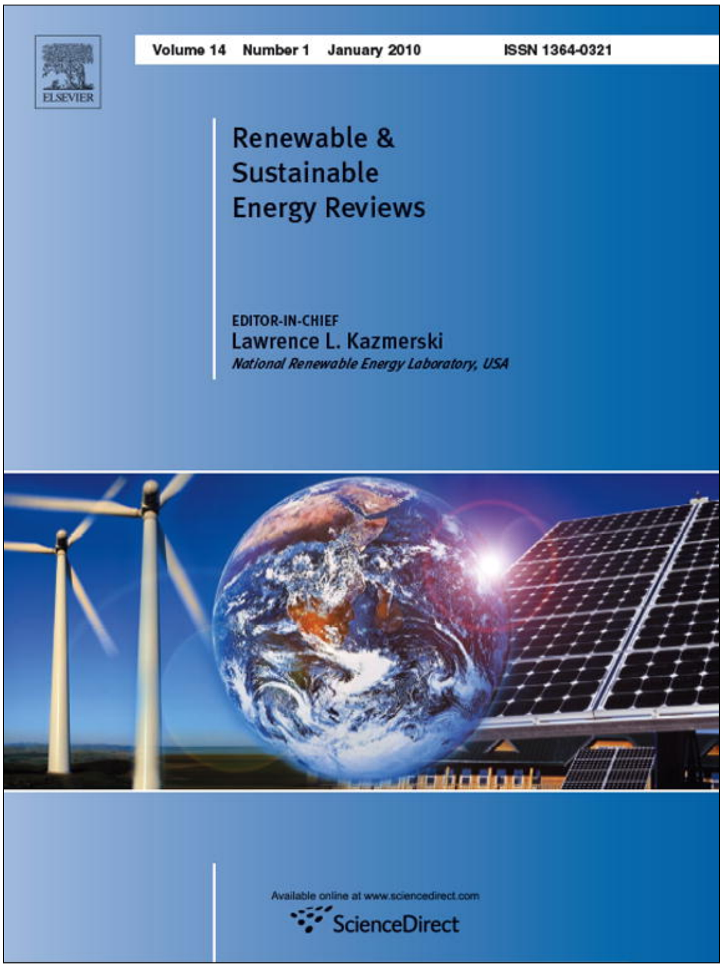
Volume 14 Number 1 January 2010
ISSN 1364-0321
ELSEVIER
Renewable &
Sustainable
Energy Reviews
EDITOR-IN-CHIEF
Lawrence L. Kazmerski
National Renewable Energy Laboratory, USA
Available online at www.sciencedirect.com
ScienceDirect

Renewable and Sustainable Energy Reviews 14 (2010) 486–492

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Environmental and economic feasibility of palm oil biodiesel in the Mexican transportation sector

Ingrid Lozada [a], Jorge Islas [b,*], Genice Grande [a]

[a] Posgrado en Ingeniería (Energía), Centro de Investigación en Energía, Universidad Nacional Autónoma de México, Privada Xochicalco S/N, Colonia Centro, Temixco, Morelos, 62580, Mexico

[b] Centro de Investigación en Energía, Universidad Nacional Autónoma de México, Privada Xochicalco S/N, Colonia Centro, Temixco, Morelos, 62580, Mexico

A R T I C L E I N F O

Article history:
Received 10 June 2009
Accepted 24 June 2009

Keywords:
Biodiesel
Palm oil
Scenarios
Mexican transportation sector

A B S T R A C T

This study analyses the environmental and economic feasibility of producing palm oil-based biodiesel in Mexico in order to substitute of diesel fuel consumption using B5 until 2015 and B10 from 2016 to 2031 in the transportation sector. Two scenarios were created by projecting demand and costs for biodiesel as well as greenhouse gases emissions reduction over the next 26 years. In the environmental section, avoided emissions of Particulate matter, Total Hydrocarbons, Carbon Monoxide, Sulphur Dioxide, and Carbon Dioxide as well as the increase in Nitrous Oxide emissions were estimated for each scenario. In the economic section, a cost–benefit analysis of biodiesel substitution was implemented, and mitigation costs of Carbon Dioxide were estimated. Our results show that the feasibility of palm oil biodiesel use is directly related to the implementation of fiscal incentives, such as the exemption from tax (Special Tax on Production and Services).

Contents

1. Introduction

Biofuel production has generated interest in several countries due to decreasing fossil fuel reserves, volatility of oil prices, climate change concerns, air pollution as well as an increasing demand for fuel in the transportation sector.

Biodiesel has been used in some countries as a substitute for diesel fuel in the transportation sector. In 2008 the production of biodiesel was increased by 180% compared to the year 2007 in the European Union. Countries with the highest production of rape-

* Corresponding author. Tel.: +52 55 56229721; fax: +52 55 56229721.
E-mail address: jis@cie.unam.mx (J. Islas).

1364-0321/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.rser.2009.06.034

seed-based biodiesel are Germany 5302 kt/year (196 PJ[1]), France 1980 kt/year (73 PJ), and Italy 1566 kt/year (58 PJ) [1]. Production of biodiesel in United States mainly derived from soybean oil was 2700 kt/year (100 PJ) in 2008, which represented an increase of 56% compared to the year 2007 [3].

The production of biodiesel from palm is a new emerging sector in the oil palm industry and at present Malaysia is the world's main producer of this biofuel wit a production of 171 kt/year (6 PJ) in the year 2008 [4]. The challenge that the use of biodiesel has faced during the last years is the pour point, which determines the feasibility for being used in cold climates, limiting its use only in tropical climates. However, according to Malaysian Palm Oil Board (MPOB) [5] a technical procedure has been developed that has turned palm oil-based biodiesel into a more versatile product, achieving a pour point of $-10\,^{\circ}C$ during spring and fall seasons, $0\,^{\circ}C$ in summer, and $-20\,^{\circ}C$ in winter.

In addition, they have been studying the technical and environmental aspects of palm oil biodiesel production to meet international standards. These studies demonstrated that it is possible to use palm oil in 2%, 5% and 10% blends, without presenting either changes in the chemical composition of the diesel or problems to the engine [6]. Since the year 2002, these blends have been used in some vehicles without showing technical problems due to the fact that both fuels (diesel and biodiesel) have similar properties [6].

Mexico is not exempt from the problem of declining proven oil reserves; and official sources estimated them in 9.2 years [7]. On the other hand, Mexico is one of the 13 countries which generated most CO_2 emissions in the world. As of year 2005, Mexico emitted 389.42[2] million tonnes of CO_2 (Mt CO_2), of which 32% were generated by the road transportation sector—7% corresponds to diesel vehicles [8]. In 2005, internal demand of diesel fuel in Mexico accounted for 26% in relation to the other fuels, and grew at an average annual growth rate of nearly 3% in the last 10 years [9].

Introduction of Biofuels in Mexico has been recently encompassed by the Law on the Promotion and Development of Bioenergy, which aims to achieve energy diversification and sustainable development as conditions that guarantee the support of Mexican agricultural sector [10].

The use of palm oil in Mexico can help reduce CO_2 emissions into the atmosphere and reduce dependence on fossil fuels in the transportation sector. Given that the main raw material is vegetable oil, biodiesel is becoming a notable factor for promoting regional development in Mexico. The oil palm is grown in the southeast region of the country, in the states of Campeche, Chiapas, Tabasco and Veracruz; its production was 292,000 t in 2007, having the highest yield and lowest unit cost of production among all oilseeds in Mexico [11]. The Mexican National Institute of Forestry, Agriculture and Livestock Research conducted a study which estimated the potential for growing oil palm, taking account of requirements such as water, temperature, soil and fertility [12]. This study found that there is an optimal gross potential of 2.5 million hectares in Mexico.

This article analyses the feasibility of using biodiesel from Palm Oil in 5% (B5) and 10% (B10) blends in the Mexican transportation sector. For this reason, the projection of an alternative scenario was made over the next 26 years (B5 from 2006 until 2015 and B10 from 2016 to 2031). This scenario was evaluated in terms of a cost–benefit analysis, the amount of pollutants reduced (Carbon Dioxide, CO_2; Carbon Monoxide, CO; Total Hydrocarbons, THC; Nitrous Oxide, NOx; Sulphur Dioxide, SO_2; and Particulate matter, PM) and the area cultivated with oil palm. Likewise, CO_2 mitigation costs were estimated, and the impact of tax incentives on the economic feasibility of biodiesel was analyzed.

2. Methodology

- Two scenarios were created. The first scenario corresponds to the trend scenario based on diesel while the other, the alternative scenario was developed in order to evaluate the feasibility to use in a large scale the biodiesel in the Mexican transport sector, and will be discussed later in this work.
- Scenarios were built and simulated using LEAP (Long-range Energy Alternative Planning System). Windows based version of LEAP has been developed by the Stockholm Environment Institute at Boston Centre (SEI-Boston). LEAP is a scenario based energy–environment modeling tool, which allows for energy policy analysis over a long-term planning horizon.
- In this study the base year is 2005, due to the fact that most recent data were available for that year.
- The period of analysis was based on a 26 years time horizon.
- Energy consumption was obtained for each scenario, while oil palm-cultivated area requirements were further obtained for the alternative scenario.
- Environmental loadings were calculated for each of the analyzed scenarios in terms of the CO_2, SO_2, and NOx emissions as well as THC and Particulate matter. On the other hand, the overall and mitigation costs of the alternative scenario were calculated.
- Finally, the economic feasibility of alternative scenario is analyzed considering the implementation of tax incentives.

3. Construction of trend scenario

Projection on diesel fuel demand is determined by taking into account the expected evolution in the vehicle fleet in Mexico.

3.1. Evolution of vehicle fleet

The first step consists of estimating the evolution of vehicle fleet in the reference year, based on the existing stock, sales and diesel vehicles that will be retired over the analysis period. This fleet was divided into the following categories: heavy-duty trucks, passenger vehicles and private cars. However, and due to the lack of data available to determine this structure, data reported by [13] were firstly used as a primary source of information for the reference year. Secondly, an alternative approach was used in order to set aside gasoline and LP gas-powered vehicles by using equivalent proportions issued by the Federal Transportation System [14] and then subtracting the number of gasoline and gas vehicles. The statistics on heavy-duty trucks, reported at federal level, are considered as a good approximation to depict the size of this fleet at national level. Finally, this approach was validated when diesel fuel demand of the vehicle fleet (437 PJ) for the reference year matched that reported in the 2005 National Energy Balance [9].

According to these calculations, 97% of diesel-powered vehicle fleet was composed of heavy-duty trucks, while passenger vehicles accounted for slightly over 2%. The remainder was private cars.

The second step consists of assigning a life cycle profile for each vehicle category so that the distribution of vehicles of different ages can be described in the reference year. Due to the fact that specific statistics on life cycle profiles are not available at national level, this profile was elaborated based on the information regarding heavy-duty trucks at federal level [14], since the vehicle fleet is mostly composed of this kind of vehicles. Finally, this approach was validated by comparing these estimations, which matched those reported in the 2002 National Inventory of Emissions [15]. Fig. 1 shows the age distribution of the heavy-duty vehicle fleet.

[1] For units conversion the calorific value of biodiesel is 37,000 kJ/kg [2].

[2] This figure represents the national emissions derived from fuel combustion. The total GHG emissions were 681 Mt CO_2 equivalent that include emissions from: fuel combustion, fugitive emissions, agriculture, waste, industrial process and others [8].

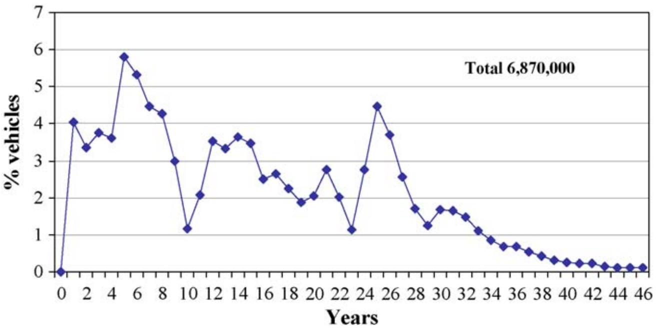

Fig. 1. Lifecycle profile of diesel-powered heavy-duty trucks. *Source*: own calculations based on data from [14] and the National Inventory of Emissions [15].

According to this estimate, it can be observed that the heavy-duty fleet is very old, since 78% of its vehicles are over 10 years old.

In the 2006–2031 period, the growth of vehicle fleet is determined by sales and the survival of vehicles as they get older. Vehicle sales totaled 450,000 for heavy-duty trucks [16], 12,500 for passenger vehicles [17], and 1000 for private cars [18] in the reference year.

With regard to the trend in vehicle sales, it is considered an average annual growth rate of 4% for both, heavy-duty and passenger vehicles, according to their historical growth [16]. On the other hand, diesel vehicles grow at a high rate of 26%, suggesting that this type of transportation would expand widely in Mexico [19]. This projection in vehicle sales is in accordance with the prospective on diesel fuel demand for the 2005–2015 period, which is expected to grow at an average annual growth rate of 4% and reaches 32% of the domestic demand for petroleum products during the same period. Thus, it is expected that heavy-duty and passenger vehicles continue to grow at their historical growth rates; however, it is foreseen a further expansion of vehicle sales, owing to the replacement of some units of the existing vehicle stock, which is mostly composed of old units. Likewise, this prospective foreseen a structural change, suggesting a considerable expansion of diesel-powered private vehicles—according to the information provided by ship owners, annual sales of diesel vehicles would total 200,000 from year 2015 [19].

In order to gradually replace existing vehicle stock, a survival profile describing the retirement of old vehicles is used. This profile represents the percent survival of vehicles as they get older as well as the percent share of vehicles that gradually will be retired from the existing vehicle stock in the country and always takes a percent share of 100% during the first year. This profile can be expressed by the following function:

$$F(t) = F(t-1)e^{tK}$$

where F is the fraction of surviving vehicles and t is the age in years of the vehicle.

$$K = \frac{\ln F(t) - \ln(F(t-1))}{t}$$

K represents a decreasing rate of the existing vehicle stock in time t, and takes a negative value.

The survival profile of heavy-duty trucks and passenger vehicles was represented by these equations. In both cases K was obtained by averaging calculations for 4 years, resulting in $K = -0.01$ and $K = -0.04$ for heavy-duty trucks and passenger vehicles, respectively. For private cars, and due to the fact that related information was not available, the value of K was assumed -0.0236, which corresponds to the one reported for gasoline vehicles in Mexico [20]. Fig. 2 shows the survival profiles of heavy-duty trucks, passenger vehicles and private cars.

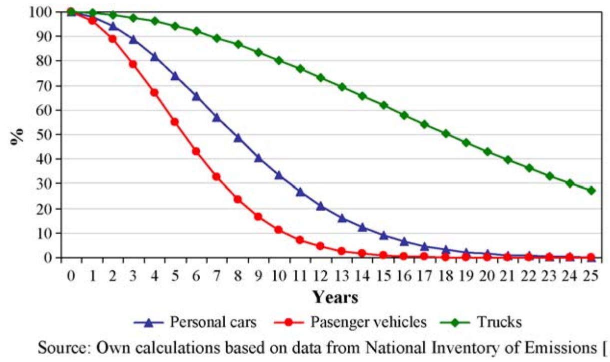

Fig. 2. Survival profiles of heavy-duty trucks, passenger vehicles and diesel private cars. *Source*: own calculations based on data from National Inventory of Emissions [15].

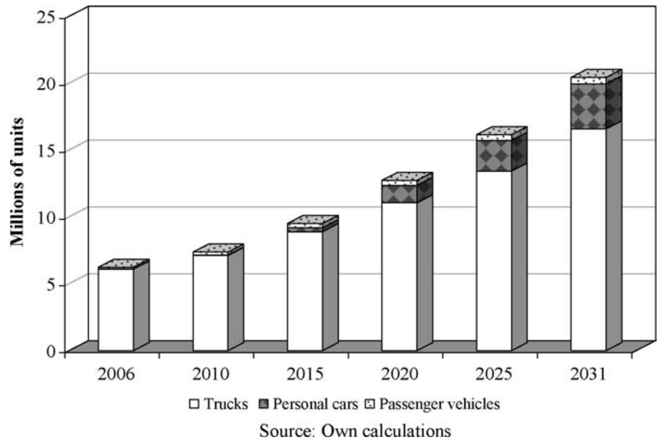

Fig. 3. Evolution of diesel-powered vehicle fleet in the Mexican transportation sector. *Source*: own calculations.

Once the survival profiles and existing stocks in the reference year as well as the annual growth in future sales have been obtained for each vehicle category, the trend in vehicle fleet is simulated using LEAP for the analyzed period. Thus, for each year of analysis, annual sales are summed to the existing vehicle stock in the reference year, while the number of vehicles that will be retired from this stock is subtracted according to the survival profile of each vehicle category.

Fig. 3 shows the trend in vehicle fleet according to the estimated average annual growth rate and the survival profile for each vehicle category.

As shown in the above-mentioned figure, in the year 2015, heavy-duty trucks, passenger vehicles and private cars would total 8.9 million, 330,000 and 290,000 vehicles, respectively. Furthermore, diesel vehicle fleet would reach 20.45 million in the year 2031, of which 16.5 million corresponds to heavy-duty trucks, 480,000 to passenger vehicles, and 3.3 million to private cars, respectively.

3.2. Estimation of diesel demand

In order to calculate the total annual diesel fuel demand in the transportation sector it is required to estimate for each vehicle category the fuel consumption of existing vehicle fleet in the year t. This is obtained from an estimate of the number of existing vehicles in the year t, their average annual mileage (in km), and the average annual diesel consumption.

Fuel consumption of heavy-duty trucks and passenger vehicles was calculated based on data reported for these vehicle categories

Table 1
Fuel consumption for each diesel vehicle category.

Vehicle category	Fuel consumption (MJ/100 km)	Annual mileage (in km)
Heavy-duty trucks	648.0	25,000
Passenger vehicles	489.6	60,500
Private cars	97.2	36,500

Source: own calculations based on data from [21] and National Inventory of Emissions [15].

in the USA [21]. The annual mileage (in km) was calculated using the average value reported in the 2002 National Inventory of Emissions. Based on this information, Table 1 was elaborated, and shows the fuel consumption for each vehicle category as well as the corresponding mileage (in km).

Based on these data, energy consumption for each vehicle category was calculated in LEAP by multiplying the existing vehicle stock in the year *t*, the annual mileage (in km), and the fuel consumption.

In trend scenario, the vehicle fleet would consume 1543 PJ by the year 2031. According to the 2005 energy prospective [19], which considers a GDP growth rate of 4.5% up to the year 2030, transportation sector would consume 3927 PJ, with diesel fuel accounting for 39% of the fuel consumed by the transportation sector during that year. Since diesel fuel production accounted for 26% of the petroleum products in the year 2005, this projection indicates that diesel would substitute gasoline by approximately 13%. In the year 2015, diesel transportation would consume approximately 861 PJ, or in other words, 34% of the total fuel consumed by the Mexican transportation sector.

3.3. Projection of diesel fuel price

To estimate the cost of diesel fuel in trend scenario it is necessary to forecast its price evolution in Mexico during the analyzed period. Since an official prospective on diesel fuel price in the Mexican transportation sector over the next 26 years was not available, the above-mentioned forecast was estimated using the price of this fuel for the Mexican electric power sector [25], and taking into account the difference between the price for power generation and transportation.

Thus, the historical difference of diesel fuel price offered to the transportation sector and that to the main power utility in Mexico (CFE) was calculated firstly. Once these price differences were calculated, a linear regression analysis was performed over the next 26 years. Finally, a projection of diesel fuel price in the transportation sector was obtained by summing the estimated price difference with the expected price reported in the high scenario of CFE for each year.

Fig. 4 shows, as calculated previously, the evolution of diesel fuel price in the Mexican transportation sector and that for the transportation sector in the USA [23]. As it can be observed, the evolution of diesel fuel price estimated in this work is similar to the one depicted for the USA, and both tend to converge, especially from the year 2020 onwards. Finally, it can also be seen that the price of diesel fuel shows an increasing trend by the year 2031, reaching $0.8[3] per liter (L).

3.4. Emission factors

In order to estimate the environmental loading associated to the trend scenario it is necessary to assign emission factors resulting from the combustion of diesel fuel. This work examines

[3] In this work the monetary unit is US dollar of year 2006.

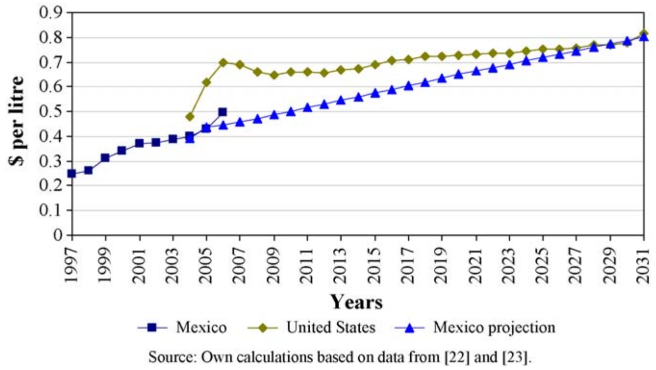

Fig. 4. Evolution of diesel fuel price in the transportation sector. *Source*: own calculations based on data from [22,23].

Table 2
Emission factors for diesel vehicles.

Year	THC	CO	NOx	PM
Heavy-duty trucks (g/MJ)				
1998	4.68	55.8	14.4	0.36
Passenger vehicles (g/MJ)				
1998	4.68	55.8	14.4	0.18
Private cars (g/vehicle-km)				
1998	0.16	2.11	0.62	0.07

Source: Refs. [24–27].

Carbon Dioxide (CO_2), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Particulate matter (PM), Total Hydrocarbons (THC), and Sulfur Dioxide (SO_2) emissions generated under this scenario.

Emission factors of CO_2 and SO_2, considered in this work, are those reported in the IPCC inventory [24]. To calculate CO, NOx, HT, and Particulate matter, EPA factors were used since current Mexican norms for diesel vehicles (NOM-044-ECOL-1993 [25], NOM-042-ECOL-1999 [26], NOM-044-SEMARNAT-2006 [27]) are referred to these standards. Table 2 shows emission factors used to estimate the environmental loading under trend scenario.

Emission factors of 72.098 g/MJ and 0.008 kg/kg of diesel consumed, were used for CO_2 and SO_2, respectively [24].

Thus, the LEAP software model calculates resulting emissions by multiplying emission factors of each pollutant by the total annual consumption of diesel. For distance-based emission factors (g/vehicle-km), they are multiplied by the total number of kilometers traveled by private cars.

4. Construction of alternative scenario

The alternative scenario identifies the main variables that determine biodiesel use when taking into account aspects related to biodiesel production and potential resources. This scenario consider the same evolution in vehicle fleet at national level, and aims at identifying the main parameters related to the substitution of diesel fuel in Mexico, especially in the frame of the Law on the Promotion and Development of Biofuels approved in 2008 [28].

Thus, the alternative scenario follows international directives on biodiesel use, since it assumes the most analyzed blend with diesel engines, i.e. 5% biodiesel and 95% diesel fuel (B5), as the one that is feasible of being implemented in Mexico. In fact, it is acknowledged at international level that the use of B5 improves diesel engines performance [2]. This is the reason why several countries have adopted this blend (India, Colombia and Malaysia, among others) as a previous stage before the use of higher blends in the coming years. In this context, the alternative scenario

Table 3
Emission reduction factors.

Emissions	B100
Total Hydrocarbons (THC)	−67%
Carbon Monoxide (CO)	−48%
Particulate matter	−47%
Nitrous Oxide (NOx)	+10%
Carbon Dioxide (CO_2)	−100%
Sulfur Dioxide (SO_2)	−100%

Source: Refs. [29–31].

considers the use of B5 from 2006 until 2015 and B10 from 2016 to 2031.

Finally, it is assumed that all requirements such as plantations and infrastructure for production and distribution of biodiesel have been developed at national level during the analyzed period.

4.1. Technical, economical and environmental characteristics of biodiesel

The alternative scenario involves the massive use of palm oil-based biodiesel. For this reason, it is necessary to consider their technical, economical and environmental characteristics, especially the calorific value, the emission and CO_2 reduction factors, and the operating and capital costs for the production of biodiesel. Particularly it is important to remark that the calorific value of biodiesel is lower (about 13% in mass terms) than that of diesel fuel [29]. Finally, emission reduction factors tank-to-wheel for biodiesel were estimated based on data from EPA (Table 3) [29–31].

This work considers that biodiesel is produced in plants with a capacity of 37,854,118 L/year, which requires investment costs of $12.112 million [32]. Furthermore, and in accordance with the property regime in Mexico, the simulation of small plants was included with the aim of considering the integration of small and medium producers and farmers.

Finally, Table 4 shows the structure of operating costs used in this work, which is based on information from national and international available data.

5. Results

This section presents the results for the alternative scenario, the biodiesel substitution in the Mexican transportation sector, when compared to the trend scenario conditions. These results provide information on energy demand, generated emissions, cost–benefit analysis and resource requirements.

Table 4
Estimated operating costs for biodiesel production in Mexico.

	Annual cost $ (in thousands)	Unit cost $/L of biodiesel
Raw materials[a]	12,907	0.340
Services[b]	542	0.014
Operation and maintenance	230	0.006
Supplies	163	0.004
Administration costs	132	0.003
Depreciation	1,206	0.032
Co-production of glycerol (kg)	1,207	0.031
Total operating costs	13,974	0.369

The following costs for raw materials (a) were considered: Methanol $0.27 kg^{-1}, Sodium Methoxide $0.95, Hydrochloric Acid $0.12 kg^{-1}, Sodium Hydroxide $0.60 kg^{-1} [32]; Palm Oil $0.289 L^{-1} (own calculations); (b) the cost of water corresponds to the tariff of industrial sector in Mexico [33]; natural gas price is based on the Henry Hub price [34]; electricity costs are based on CFEs intermediate tariff applicable for end users with a consumption above 100 kW in the southern region of Mexico [35], and $0.33 kg^{-1} for glycerol recovery with a purity of 80% [32].

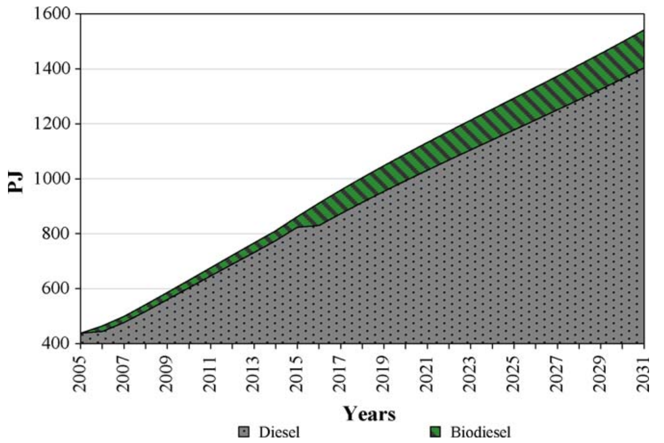

Fig. 5. Energy consumption under the alternative scenario in the Mexican transportation sector.

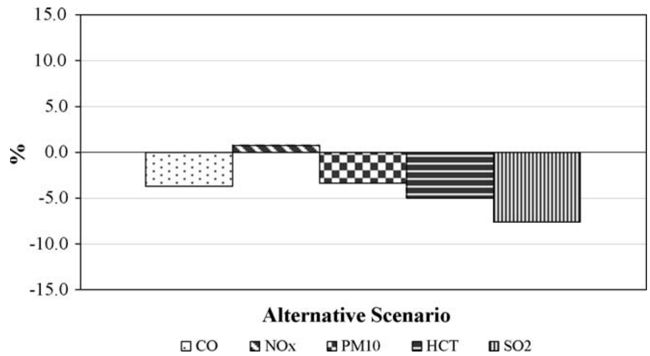

Fig. 6. Avoided and generated emissions under biodiesel alternative scenario.

5.1. Energy demand

Fig. 5 shows the penetration of biodiesel in the energy consumption of the transport sector in the alternative scenario, which reaches roughly 9% of the total consumption in 2031. In terms of the energy substitution during the analyzed period, biodiesel is expected to replace 7.8% of diesel fuel consumption in the alternative scenario.

In order to meet this demand, it would be required not only the capacity expansion of existing extraction facilities, but also the construction of biodiesel plants. Thus, and considering small biodiesel plants with a production capacity of 37,854,118 L/year, by 2015, 32 new plants would be required in the alternative scenario. As of year 2031, 113 biodiesel plants would be required in this scenario. The cumulative investment costs of these plants would be approximately $765 million.[4]

5.2. Emissions reduction

Cumulative CO emissions would be reduced by 4184 million kilograms (Mkg) in the alternative scenario that represent a reduction of 3.7% of total CO emissions. Reduction of Particulate matter would be 26 Mkg, which accounts for cumulative reductions of 3.4% for the alternative scenario. Reduction of Total Hydrocarbons would account for 5% (479 Mkg).

[4] In this article, a discount rate of 10% was considered.

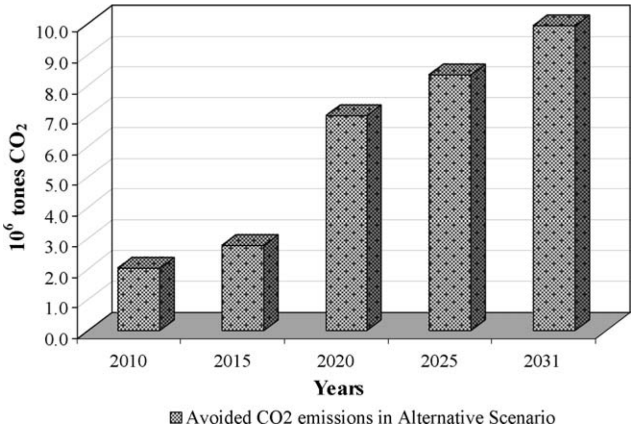

Fig. 7. Avoided CO_2 emissions under biodiesel alternative scenario.

With regard to SO_2 emissions, it can be observed an important reduction in the alternative scenario, reaching approximately 380 Mkg (7.6%).

Fig. 6 shows the amount of pollutants emitted in alternative scenario. The percent share indicates either a reduction or an increase in relation to the trend scenario.

On the contrary, NOx emissions would be increased by 220 Mkg in the alternative scenario. This increase would also account for 0.7% of these emissions.

Finally, the most important reduction was found for CO_2 emissions. Fig. 7 shows avoided CO_2 emissions due to the use of biodiesel. As it can be observed in this figure, in the alternative penetration scenario emissions would be reduced by 3 million tonnes by 2015, while this reduction would reach roughly 10 million tonnes by 2031. This reduction would also account for 4.5% and 8.9% in relation to those emissions of trend scenario. Finally, during the analyzed period the reduction could arrive to 148 million tonnes of CO_2 emissions in the alternative scenario, which represents a global reduction of 7.7%.

5.3. Cost–benefit analysis and CO_2 mitigation costs

Our calculations show that biodiesel use—when compared with the costs of diesel fuel—would represent overall costs of 2000 million dollars in the alternative scenario. Table 5 shows these results; the first row refers to the avoided costs of diesel fuel and the second one the costs of using biodiesel. It is important to note that the costs of using biodiesel, in relation to the diesel fuel costs of the trend scenario, are presented with positive values. These results clearly indicate that in this case, which depict their production costs, the biodiesel use represents costs.

Furthermore, mitigation costs would total $49 per tec (tonne of equivalent carbon). The mitigation costs of biodiesel were obtained by dividing overall costs and cumulative CO_2 emissions for each scenario.

Table 5
Cost–benefit analysis and mitigation costs of biodiesel (biodiesel costs vs. diesel fuel costs).

Alternative scenario	Thousand million $
Avoided costs of diesel fuel in refineries	−4.6
Production cost of biodiesel	6.8
Overall costs	2.2
Avoided CO_2 (million tonnes of equivalent carbon)	40.5
Mitigation costs (U.S. dollars per tonne of equivalent carbon)	54

Table 6
Cost–benefit analysis and mitigation costs of biodiesel prices (including VAT plus distribution costs but exempting the Special Tax on Production and Services) vs. diesel fuel prices.

Alternative scenario	Thousand million $
Consumer price of diesel fuel	−9.0
Consumer price of biodiesel[a]	7.9
Overall costs	−1.2
Avoided CO_2 (million tonnes of equivalent carbon)	40.5
Mitigation costs (U.S. dollars per tonne of equivalent carbon)	−30

[a] Considering a VAT of 15%.

Nevertheless, we found that if diesel and biodiesel prices (including the VAT of 15%, an average distribution cost of 15 USD/m^3 but exempting the Special Tax on Production and Services (IEPS) in the biodiesel scenario) are compared. In this case, the use of B5 and B10 would lead to benefits of 1.2 thousand million dollars in the alternative scenario (see Table 6). When comparing the price of diesel fuel and the price of biodiesel, there are negative values in the mitigation costs.

These results indicate that biodiesel would be competitive with diesel fuel without the exemption from VAT. However, results clearly indicate that this would be possible provided that biodiesel could be exempted from the Special Tax on Production and Services (IEPS), or in other words, if the Mexican government grants a fiscal incentive for biodiesel. Conversely, the implementation of the IEPS would make it very costly, since this tax imposed on diesel fuel has accounted for 50% of consumer's price in Mexico [36].

5.4. Resource analysis and job creation

In order to meet each scenario's demand for biodiesel, it is necessary to estimate the required biomass resources, which in turn implies an increase in cultivated areas of oil palm. Current yield of this type of plantation is approximately 2915 L/ha [37]. For simulation purposes, this yield is considered to be improved as long as plantations reach maturity, i.e. 20 t of fresh fruit bunches (FFB) per hectare or 3239 L/ha.

Fig. 8 shows resource requirements in thousands of cultivated hectares as well as the corresponding annual energy content of oil palm production in PJ for the analyzed scenario. As it can be observed, it is required approximately 1 million hectares of cultivated area in 2031 to satisfy the biodiesel demand. It is important to remark that this cultivated area is far below the good resource potential, described in previous sections.

These results indicate that the implementation of the alternative biodiesel scenario would be feasible in order to meet with

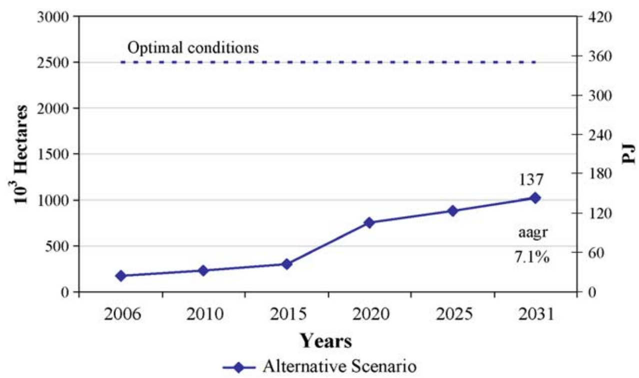

Fig. 8. Area requirements for oil palm production in Mexico.

palm oil-based biodiesel demand in the Mexican transportation sector.

With regard to job creation, the cultivation of oil palm may lead to the creation of about 922,000 direct jobs in the alternative scenario. These results are based on the assumption that a crop hectare creates 0.3 and 0.6 direct jobs in the agricultural and industrial sectors, respectively [38].

6. Conclusions

The results obtained in this work indicate that oil palm resources, under the assumption of a good resource potential, are more than enough to cover the needs of the alternative scenario (B5 from 2006 until 2015 and B10 from 2016 to 2031).

During the whole period of analysis, cumulative emissions reductions would total 3.4% and 3.7% for Particulate matter and CO, respectively. Additionally, Total Hydrocarbon emissions would be reduced by 5%, while SO_2 emissions reduction would total 7.6% in relation to the trend scenario.

In contrast, biodiesel use would lead to an increase of 0.7% in NOx emissions, which requires the installation of catalytic converters in biodiesel-powered vehicles so that these emissions can be reduced by 80–90%.

CO_2 emissions would be considerably reduced when using biodiesel in the alternative scenario, and would reach cumulative reductions of 148 million tonnes.

Finally, the cost–benefit analysis points out that the substitution of diesel fuel for palm oil-based biodiesel is feasible when a tax-exemption policy (e.g. exemption of IEPS) is implemented.

Acknowledgments

This work was supported by SEMARNAT through Research Grant No. 2004-C01-443/A-1. Ingrid Lozada is thankful to DGEP-UNAM for providing postgraduate scholarship and Genice Grande acknowledges the support from CONACYT through postgraduate scholarship. Finally, the authors thank to Fidel Carrasco for his editorial assistance.

References

[1] European Biodiesel Board (EBB). Biodiesel Production Statistics; 2009. Available at: http://www.ebb-eu.org/stats.php (accessed January 2009).
[2] International Energy Agency (IEA). Special Issue Paper 8 Net Calorific Values. Energy Statistics Working Group Meeting, IEA; 2004. Available at: http://www.iea.org/textbase/work/2004/eswg/21_NCV.pdf (accessed October 2007).
[3] National Biodiesel Board (NBB), 2009. Available at: http://www.biodiesel.org (accessed January 2009).
[4] Malaysian Palm Oil Board (MPOB), 2009. Available at: http://www.mpob.gov.my (accessed January 2009).
[5] Yuen C, Ah M, Kien C, Abdul R, Yap A, Lau H, et al. Palm diesel: green and renewable fuel from palm oil. Malaysian Palm Oil Board; 2002. Available at: http://www.americanpalmoil.com/pdf/biodiesel/green and renewable fuel.pdf (accessed October 2007).
[6] Basiron Y, Yuen C. Crude palm oil as a source of biofuel: its impact on price stabilization and environment. Malaysian Palm Oil Board; 2004. Available at: http://www.mpob.gov.my/bfuel_poil1.pdf (accessed February 2007).
[7] Petróleos Mexicanos (PEMEX). Reservas de hidrocarburos al 31 de diciembre de 2007. PEMEX, Mexico; 2008. Available at: http://www.pemex.com/files/dcf/Reservas2007_e_080326.pdf (accessed April 2008).
[8] International Energy Agency (IEA). CO_2 emissions from fuel combustion 1971–2005. Paris, France: OECD/IEA; 2007.
[9] Secretaría de Energía (SENER). Balance Nacional de Energía 2005. Mexico: SENER; 2006.
[10] Diario Official de la Federación (DOF). Ley de Promoción y Desarrollo de los Bioenergéticos; 2008. DOF. Published on February 1, 2008. Available at: http://www.energia.gob.mx/webSener/res/Acerca_de/SENER01022008.pdf (accessed March 2008).
[11] Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA). Sistema de Información Agroalimentaria y Pesquera-SIAP. Mexico: SAGARPA. 2009 Available at: http://reportes.siap.gob.mx/aagricola_siap/ientidad/index.jsp (accessed January 2009).
[12] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Tecnología para la producción de palma de aceite *Elaeis guineensis Jacq.* en México. 2a ed. México: INIFAP; 2006. 149 p.
[13] Instituto Nacional de Estadística y Geografía (INEGI). Sistema Nacional de Información Estadística y Geográfica. Mexico: INEGI; 2007. Available at: http://dgcnesyp.inegi.org.mx/cgi-win/bdiecoy.exe/522?s=est&c=13103 (accessed March 2007).
[14] Secretaría de Comunicaciones y Transportes (SCT). Estadísticas autotransporte federal de carga en México. Mexico: SCT; 2007. Available at: http://dgaf.sct.gob.mx/index.php?id=466 (accessed March 2007).
[15] Instituto Nacional de Ecología (INE). Inventario Nacional de Emisiones de Gases de Efecto Invernadero. Mexico: INE; 2007 (accessed March 2007).
[16] Instituto Nacional de Estadística y Geografía (INEGI). Balanza Comercial de México. Mexico: INEGI; 2007. Available at: http://www.inegi.gob.mx/prod_serv/contenidos/espanol/bvinegi/productos/continuas/economicas/exterior/mensual/bcm/bcm.pdf (accessed March 2007).
[17] Asociación Nacional de Productores de Autobuses, Camiones y Tractocamiones (ANPACT). Estadísticas: Ventas mercado nacional de vehículos pesados histórico. Mexico: ANPACT; 2007. Available at: http://www.anpact.com.mx/estadistica/ventas/vtahist.htm (accessed April 2007).
[18] Volkswagen México, 2007. Available at: http://www.volkswagen.com.mx (accessed April 2007).
[19] Secretaría de Energía (SENER). Prospectiva de petrolíferos 2005–2014. Mexico: SENER; 2006.
[20] Manzini F. Inserting renewable fuels and technologies for transport in Mexico City Metropolitan Area. Internacional Journal of Hydrogen Energy 2007;31:327–35.
[21] Giannelli R, Nam E, Helmer Y, Younglove T, Scora G, Barth M. Heavy-duty diesel vehicle fuel consumption modeling based on road load and power train parameters. USA. Paper offer #05cv-3, 2005.
[22] Comisión Federal de Electricidad (CFE). Evolución de precios entregados y fletes de combustibles. Mexico: CFE; 2004.
[23] Energy Information Administration (EIA). Annual Energy Outlook 2007; 2007. United States: DOE/EIA. Available at: http://tonto.eia.doe.gov/dnav/pet/hist/rwtca.htm (accessed April 2007).
[24] Intergovernmental Panel on Climate change (IPCC), 1996. Database on greenhouse gas emission factors, vol. 3, reference manual. 1996 revision.
[25] Diario Official de la Federación (DOF). Norma Official Mexicana NOM-044-ECOL-1993; 1993. Published October 22, 1993. Available at: http://dof.gob.mx/nota_to_imagen_fs.php?cod_diario=209192&pagina=2&seccion=1 (accessed May 2007).
[26] Diario Official de la Federación (DOF). Norma Official Mexicana NOM-042-ECOL-1999; 1999. Published September 6, 1999. Available at: http://dof.gob.mx/nota_to_imagen_fs.php?cod_diario=148672&pagina=3&seccion=1 (accessed May 2007).
[27] Diario Official de la Federación (DOF). Norma Official Mexicana NOM-044-SEMARNAT-2006; 2006. Published October 12, 2006. Available at: http://dof.gob.mx/nota_to_imagen_fs.php?cod_diario=210149&pagina=2&seccion=1 (accessed May 2007).
[28] Diario Official de la Federación (DOF). Decreto por el que se expide la Ley de Promoción y Desarrollo de los Bioenergéticos; 2008. Published February 1, 2008. Available at: http://dof.gob.mx/nota_detalle.php?codigo=5029330&fecha=01/02/2008 (accessed March 2008).
[29] Canakci M. Combustion characteristics of a turbocharged DI compression ignition engine fueled with petroleum diesel fuels and biodiesel. Bioresource Technology 2007;98:1167–75.
[30] Environmental Protection Agency (EPA). A comprehensive analysis of biodiesel impacts on exhaust emissions. Draft Technical Report Office of Transportation and Air Quality U.S. NBB/EPA, EPA420-P-02-001; 2002.
[31] Körbitz W. Biodiesel production in Europe and North America. An encouraging prospect. Renewable Energy 1999;6:1078–83.
[32] Haas MJ, McAloon A, Yee W, Foglia T. A process model to estimate biodiesel production costs. Bioresource Technology 2006;97:671–8.
[33] Instituto Nacional de Estadística y Geografía (INEGI). Información Estadística: Agua; 2007. Mexico: INEGI. Available at: http://www.inegi.org.mx/inegi/default.aspx?s=est&c=6159 (accessed May 2007).
[34] Natural Gas Prices. Henry Hub Natural Gas Prices; 2007. Available at: http://naturalgasprice.net (accessed June 2007).
[35] Comisión Federal de Electricidad (CFE). Tarifas para el suministro y venta de energía eléctrica. Mexico: CFE; 2007. Available at: http://www.cfe.gob.mx/es/InformacionAlCliente/conocetutarifa/ (accessed May 2007).
[36] Asociación Nacional de Transporte Privado (ANTP). Usuarios del transporte de carga en México; 2006. Available at: http://www.antp.org.mx/ieps/prepet04.pdf (accessed June 2007).
[37] Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación (SAGARPA). Plan rector del sistema productor palma de aceite de Chiapas 2004–2014. Mexico: Fomento económico de Chiapas/Gobierno de Chiapas; 2004.
[38] Colombia Presidencia de la República. Available at: http://web.presidencia.gov.co (accessed June 2007).